(2)168—173

STUDY ON THE STOCHASTIC CHAOS IN LASER-DNA INTERACTIVE SYSTEM *

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Abstract *By studying the numerical calculation of the stochastic-dynamics equation of the laser-DNA interaction*, it was found that with the approximation of small signal and adiabatic hypothesis and under suitable conditions, the stochastic chaos will occur in the laser-DNA interactive system. The appearance of stochastic chaos is related to the intensity of laser. When it is very weak there is no chaos and this suggests that small intensity of laser does not make DNA mutate. When laser intensity reaches a certain value, chaos appears and makes DNA mutate. With the increase of laser intensity, the characteristic of chaos in the evolution process of system becomes more and more significant. However, laser intensity can not be too strong, otherwise it will cause very complex chaos that makes a severe problem of uncertainty in laser breeding and brings uncontrollable results instead of inducing DNA to mutate. The influence of the periodical change of environment on laser-DNA interactive system was discussed, too.

Key words DNA, Fokker-Planck equation, nonlinearity, stochastic chaos.

激光与DNA作用系统的随机混沌研究*

TN249, Q631, Q523,

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摘要 通过对激光与DNA分子相互作用系统的随机动力学方程数值研究,发现在小信号绝热近似下,适当条件时,出现随机混沌.随机混沌的出现与激光强度有关,当激光强度很小时,无混沌现象出现,意味着小激光强度不能激励DNA发生变异.当激光强度达到一定值时,出现了混沌,会激励DNA发生变异.并随着激光强度的增大,体系的演化过程的混沌特征就越来越明显.但同时太强的激光强度引起的混沌非常复杂,会使激光与DNA作用系统的随机不确定性严重,带来难以控制的后果,可能反而会使DNA不产生变异.本文还讨论了激光与DNA相互作用系统受环境周期变化的影响.

关键词 DNA, Fokker-Planck方程,非线性,随机混沌.

激光

INTRODUCTION

Biosystem is a complicated nonlinear system, so we should use nonlinear theory to study its kinetics. With chaos theory we studied the laser-DNA interaction and obtained that the laser's action makes DNA system enter into chaos, breaking up the original state of moment in order and interfering genetic information, thus resulting in genetic mutation. In the course of primary research, we found that the randomness exists in the laser-DNA interaction system[1]. Under the approximate condition of small signal and adiabatic hypothesis, when the effect of random forces on laser-DNA interaction system is taken into account, stochastic resonance happens. The laser-DNA interaction is related to the noise

* The project supported by the Natural Science Foundation (No. JW 970022) of Education Committee of Jiangsu Province, China
Received 1999-11-05, revised 2000-02-13

* 江苏省教委自然科学基金(JW 970022)资助项目
稿件收到日期 1999-11-05,修改稿收到日期 2000-02-13

strength, laser amplitude of vibration and its frequence[2]. Our further study in this paper suggests that, when the laser-DNA system is affected by both periodic driving forces and stochastic forces, biosystem is actually a nonlinear random vibrating system. In proper conditions, the laser-DNA interaction system takes on either random resonance or stochastic chaos, however, the latter reveals the complexity of biosystem further. Finally the influence of external environment and some other periodic driving forces on biosystem is discussed, too.

1 Stochastic Chaos

Chaos, one of the characteristics of nonlinear system, has a basic feature, i. e. extreme sensitivity to initial value, which has been verified in many other nonlinear systems. Its response is uncertain to the final result. Stochastic chaos means the phenomenon of chaos in the random systems.

Based on Yomosa's basic rotor model, the equation of movement including interaction among laser, random forces and DNA molecules was derived under approximate condition of small amplitude[3]:

$$\dot{x} = -a(x - \frac{1}{6}x^3) + A\cos\omega t + \Gamma(t), \qquad (1)$$

where we supposed that the stochastic force $\Gamma(t)$ in Eq. (1) is Gruse noise, $\langle\Gamma(t)\rangle = 0$, $\langle\Gamma(t)\Gamma(t')\rangle = 2D\delta(t-t')$, $x=\varphi$, $\dot{x}=\dot{\varphi}$; the definitions and initial values of a、A could be found in Ref. [1]. Equation (1) can be transformed into Fokker－Planck equation:

$$\frac{\partial P(x,t)}{\partial t} = -\frac{\partial}{\partial x}[-u'(x) + F(t)]P(x,t) + D\frac{\partial^2}{\partial x^2}P(x,t) = \hat{L}(x,t)P(x,t), \qquad (2)$$

where,

$$\hat{L}(x,t) = -\frac{\partial}{\partial x}[-u'(x) + F(t)] + D\frac{\partial^2}{\partial x^2},$$

$$u(x) = -a(\frac{1}{2}x^2 - \frac{1}{24}x^4) + cx,$$

$$F(t) = A\cos\omega t.$$

Since Eq. (2) is similar to the Schrödinger equation, generalized momentum operator $\hat{P}$ is introduced, $\hat{P}=$

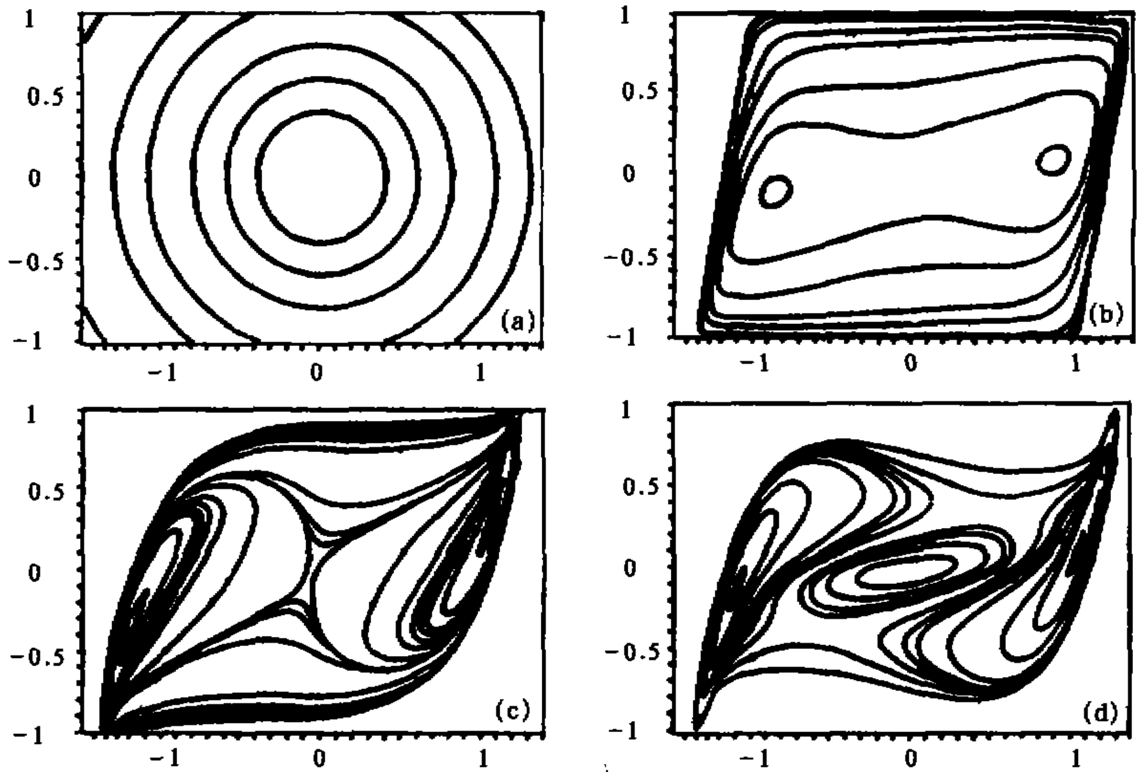

Fig. 1 The phase diagram of the solutions of Eq. (4), with $a=0.01$, $c=0$, $D=0.20$, $\omega'=0.03$
(a) $A=0.001$, (b) $A=0.01$, (c) $A=0.02$, (d) $A=0.10$

图1 在 $a=0.01$, $c=0$, $D=0.20$, $\omega'=0.03$ 时,式(4)解的相图

$2Di\frac{\partial}{\partial x}, i=\sqrt{-1}$, so Hamilton is taken as:

$$\hat{H}=\frac{\hat{P}^2}{2}+U(x,t), \quad (3)$$

where,

$$U(x,t)=D(-\frac{a}{2}x^2+a)+(\frac{a}{6}x^3-ax+c)^2+A(-\frac{a}{6}x^3+ax-c)\cos\omega t+\frac{1}{2}A^2\cos^2\omega t-A\omega x\sin(\omega t).$$

The solution of Eq. (3) is hypothetical,

$$\Psi(x,t)=\sum_a\psi_a(x,t)e^{\lambda_a t},$$

where $\Psi_a(x,t)$ and λ_a are adapted to the following equation

$$\left[\hat{H}_0(x)+U(x,t)+2D\frac{\partial}{\partial x}\right]\psi_a(x,t)=\lambda_a\psi_a(x,t). \quad (4)$$

$\Psi_a(x,t)$ and λ_a can be obtained from Eq. (4) using finite-element method. Figures 1 and 2 show that the appearance of chaos is related to the intensity of laserduring the laser-DNA interaction. Where there exists small laser intensity there is no chaos, which means small intensity of laser couldn't make DNA mutate. When laser intensity reaches a certain value, chaos appears, and with the increase of laser intensity, the characteristic of chaos in the process of system evolution becomes more and more significant. In other words, if laser intensity is too weak and power density is too low, mutation of DNA molecules can not occur. So there exists a threshold.

Chen[4] pointed out that the application of laser to silkworm industry showed that when invariable laser wavelength irradiated larvae, small doses didn't bring about genetic mutation, when doses increased to a certain degree, genetic mutation happened. Chen[4] pointed that the laser-induced mutation of domestic silkworm had a good effect under large-dose irradiation of one whole pulse, i. e. mutation happened; while under accumulative irradiation of pulses with equal weak energy, it didn't appear, the reason of which is that although equal-radiation energy density is offered, the power density is different, the latter is far lower than the former. In order to guarantee the efficiency of laser-induced mutation, enough power density is necessary, and many theories and researches show that there exists a threshold.

However, laser intensity could not be too strong, otherwise it will cause very complex chaos that makes severe problem of uncertainty in laser breeding and brings many uncontrollable consequences (See Figs. 1 and 2); meanwhile it could not induce DNA to mutate, so chaos must be limited to some extent. Tangmin *et al.* [5] pointed out that in the research of amount of mouse brainblood, quite different biological effects with different mutation were discovered after processing with same wavelength and different power density, which means that it is necessary to choose proper laser intensity. Maybe it is one of the ways to control random uncertainty.

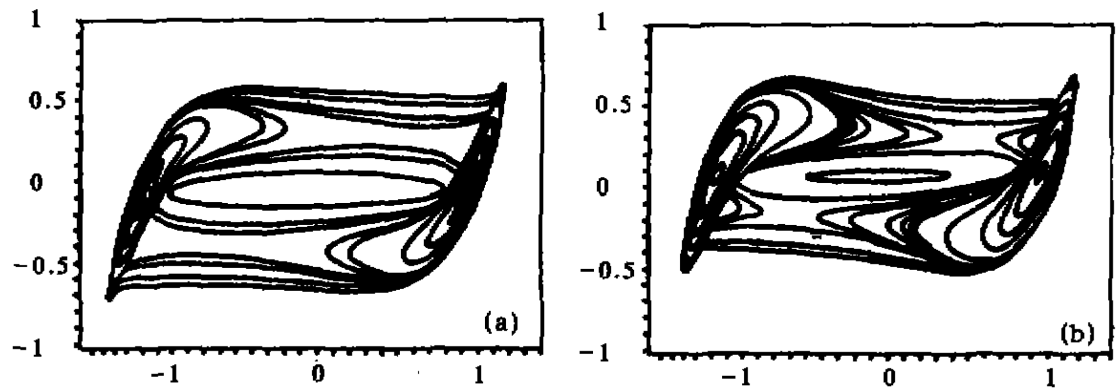

Fig. 2 The phase diagram of the solutions of Eq. (4) with $a=0.01$, $c=0$, $D=0.30$, $\omega'=0.05$
(a) $A=0.04$, (b) $A=0.20$

图 2 在 $a=0.01, c=0, D=0.30, \omega'=0.05$ 时，式(4)解的相图

2 Laser-DNA System under Multiple Periodic Forces Driving

In the processes of laser processing on DNA molecules, effects of other periodic forces of environment (temperature, atmosphere pressure, etc.) must be taken into account, so Eq. (1) may be rewritten as:

$$\dot{x} = -a(x - \frac{1}{6}x^3) + A_1\cos\omega_1 t + A_2\cos\omega_2 t + \Gamma(t). \quad (5)$$

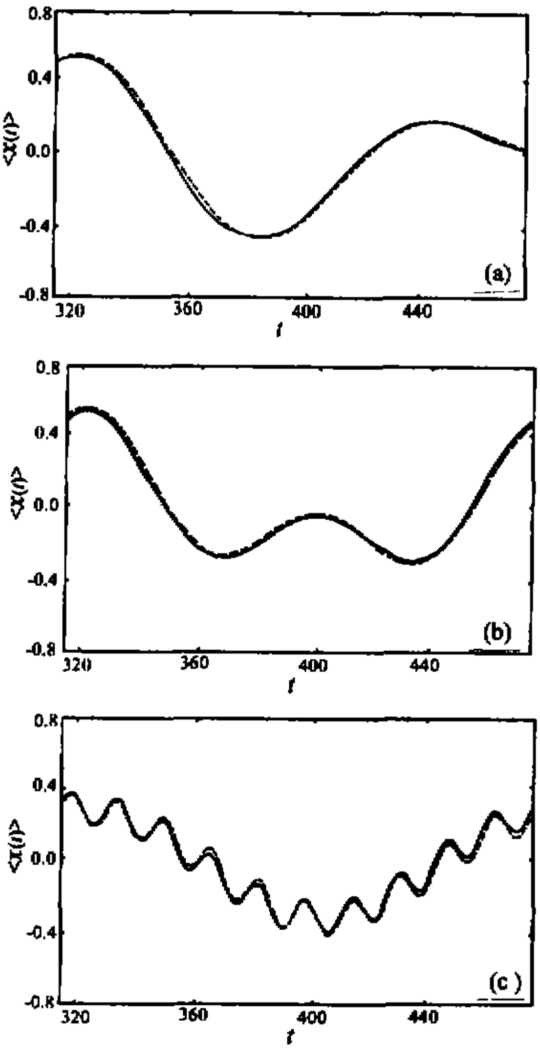

Fig. 3 The average value outputting $<x_1(t)+x_2(t)>$ compared with $<x_1(t)>+<x_2(t)>$ for noise strength $D=0.20$; σ is error, $\omega'_1=0.84$ (a) $\omega'_2=0.06$, $\sigma=0.019$; (b) $\omega'_2=0.08$, $\sigma=0.015$; (c) $\omega'_2=0.04$, $\sigma=0.018$

图 3 在 $\omega'_1=0.84$,噪声强度 $D=0.20$ 时,平均输出响应 $<x_1(t)+x_2(t)>$(虚线)与 $<x_1(t)>+<x_2(t)>$(实线)的比较,σ 为偏差

The Fokker-Planck equation corresponding to Eq. (5) becomes

$$\frac{\partial P(x,t)}{\partial t} = -\frac{\partial}{\partial x}[-a(x - \frac{1}{6}x^3 + A_1\cos\omega_1 t + A_2\cos\omega_2 t)]P(x,t) + D\frac{\partial^2}{\partial x^2}P(x,t). \quad (6)$$

2.1 Simple harmonic as $A_2=0$

Under small signal and adiabatic approximation, Lu Zhiheng *et al.*[6] studied in detail Eq. (6) as $A_2=0$, $A_1\to 0$, $\omega'_1 \ll D$, $D \ll \Delta V$ (ΔV stands for the difference between double stationary state barrier height) and obtained linearly approximate theory.

$$<x_1(t)> = \frac{A_1 <1|\frac{\partial}{\partial x}|0><0|x|1>}{\sqrt{\lambda_1^2 + \omega'^2_1}}\cos(\omega'_1 t + \alpha_{1,1}). \quad (7)$$

Equation (7) indicates that the solution of Eq. (6) is harmonic. We can reduce Eq. (7) further into

$$<x(t)> = x_0\cos(\omega'_1 t + \psi), \quad (8)$$

where,

$$\begin{cases} x_0 = \dfrac{<1|\frac{\partial}{\partial x}|0><0|x|1>}{\sqrt{\lambda_1^2 + \omega'^2_1}}A_1, \\ \psi = \alpha_{1,1}. \end{cases} \quad (9)$$

Although the instantaneous signal $x(t)$ of laser-DNA interaction system should satisfy nonlinear equation (6), its average value, due to its simple harmonic, may be considered in form as a solution to some linear vibration equation, e.g.,

$$\frac{\partial^2 \bar{x}}{\partial t^2} + 2B\frac{\partial \bar{x}}{\partial t} + \omega_0^2 \bar{x} = A\cos\omega'_1 t. \quad (10)$$

Attention should be paid to the physical meaning of the original point $x=0$. For Eq. (6), suppose that noises don't exist, $\Gamma(t)=0$, where $x=0$ is an unstable state. Once a system is put on this position, under the action of double stationary barrier, it should leave the point immediately. But to the statistical value $<x(t)>$ containing the system of random forces, it will have a different expression, Eq. (10). x will vary around the position $x=0$, that is, $x=0$ is equivalent to the stable position of random resonance in the sense of average value. The main difference lies in the latter consideration of functions of random forces $\Gamma(t)$. Therefore, as recovering force to the system from deviating balance position, the random force makes system express linear vibration with $x=0$ as its balance position.

2.2 Simple harmonic as $A_2 \neq 0$

When $A_2 \neq 0$, under small signal adiabatic approximation, our research indicated that the solution of Eq. (6) may be obtained by linear theory and approved by numerical calculation.

$$\bar{x}(t) = x_{10}\cos(\omega'_1 t + \varphi_1) + x_{20}\cos(\omega'_2 t + \varphi_2) \tag{11}$$

Figure 3 shows that $<x_1(t)+x_2(t)>$ (dotted line) coincides with $<x_1(t)>+<x_2(t)>$ (solid line), their deviation is less than 2%, i. e., the response to average output of periodic forces abides by iterative theory.

3 Discussion and Conclusion

Under adiabatic approximation, random chaos comes into being in the interaction of laser-DNA, and is related with laser intensity. This, on the one hand, shows that when laser intensity surpasses a certain threshold, DNA may mutate under the action of laser, on the other hand, indicates that laser breeding holds uncertainty of randomness, which makes difficult prediction of the final results. So it is necessary to properly selcet laser intensity and does.

The output statistical average value under the driving of multiple periodic forces could be obtained by accumulating output average value in the respective driving of many single periodic forces. It is still discovered that, the greater the noise strength is, the better the accumulation identifies with. Discussion on accumulativeness of system average value is undoubtedly a new probe to stochastic resonance system theory.

Further study proposes that, when $\omega'_1=\omega'_2$, $A_1>A_2$, the outside environmental periodic forces could be omitted; when $A_1=A_2$, if $\omega'_2 \gg \omega'_1$, it may also be omitted, that is, short-period driving forces contribute little. In fact the frequency of laser is far higher than that frequency of outside environment, so outside influence is under no consideration. However, when $A_1<A_2$, the outside environment driving forces are important in the laser-DNA interation system.

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